SECTION 1.0

GEOLOGY

1.0 GEOLOGY

This section presents a compilation of geologic data obtained during various investigative phases conducted for construction and operation of a Class III solid waste landfill on the Gregory Canyon property (the Gregory Canyon Landfill).

1.1 INTRODUCTION

The main objectives of the geologic phase of the investigation were to define the site setting and geologic units, review the seismic setting of the site, and evaluate potential geologic hazards associated with siting a landfill in Gregory Canyon. This information provides the basis for the landfill design and construction as discussed later.

Location and Topography

The site is located in the central portion of the Peninsular Ranges province, which is characterized by northwesterly trending mountains and intervening valleys. This geomorphic province extends from the Los Angeles Basin into Baja California, Mexico. Major drainage systems generally traverse the province in a westerly direction and in northern San Diego County include, from north to south, the Santa Margarita, San Luis Rey and San Dieguito rivers. The proposed landfill site is located in Gregory Canyon, a north-draining tributary canyon south of the tributary to San Luis Rey River valley.

For the last 20 million years, the tectonic "grain" of the Peninsular Ranges province has been dominated by strike-slip faulting along northwest-trending faults like the San Andreas, San Jacinto, Elsinore, and Rose Canyon faults. The Elsinore fault zone is located about six miles northeast of Gregory Canyon, and is thus the closest of these large structural discontinuities to the site (Figure 1-1). Like the rest of these faults, the Elsinore fault zone is the result of the right-lateral slip between the North American and Pacific plates, though individual fault strands within the Elsinore fault zone may have strike-slip, normal or thrust fault motions due to complex local fault geometries (Lamar and Rockwell, 1986). The northwest-trending fabric of the fault zone results in distinctive structural features, including large-scale structural depressions like the Elsinore Trough, and structural highs such as the Agua Tibia Mountains.

Regional topography in the Peninsular Range is characterized by considerable relief with relatively moderate to steep slopes. Most of the area is undergoing erosion and mass wasting, but the major river valleys have thick accumulations of sediments, technically referred to as alluvium. The alluvium undergoes cycles of deposition and erosion, depending on the water flow in the drainage system. Typically, the rivers are at low flows during the summer months and have variable flows during the winter rainy season.

The proposed landfill site is located in Gregory Canyon, a north-draining tributary canyon to the San Luis Rey River valley (Figure 1-1). The thalweg of the canyon drops in elevation from about 920 feet amsl at the head of the canyon on the south, to about 320 ft amsl on its northern terminus. East of the Gregory Canyon, Gregory Mountain rises steeply to a maximum elevation of 1844 feet above mean sea level (amsl). The western ridge is less steep, and rises to a maximum elevation of only 940 feet amsl.

Gregory Canyon side slopes are about 5:1 (horizontal:vertical) near the canyon thalweg, become 2:1 at the east edge of the proposed landfill footprint, and are often 1:1 or steeper on the upper part of the eastern slope above the site. The western flank of the canyon is defined by a rounded ridge line, with rather uniform slopes at inclinations of 2:1 to 3:1.

1.2 GEOLOGIC UNITS

The following sections summarize the regional and local geologic units based on a review of literature and site mapping performed at the site, and as presented previously in the Phase 6 Geotechnical Investigation (GLA, 1998).

1.2.1 Regional Stratigraphy

Pre-batholithic, metasedimentary and metavolcanic rocks outcrop throughout the Peninsular Ranges. In San Diego County, outcrops include the Triassic/Jurassic Bedford Canyon sedimentary sequence and the overlying Jurassic Santiago Peak volcanics.

Late Cretaceous sedimentary rocks in the Camp Pendleton area include the largely non-marine Trabuco Formation, and the marine Williams Formation, which in the San Luis Rey and Encinitas areas, are grouped in the Lusardi and Point Loma Formations. Cretaceous rocks are not exposed in the immediate vicinity of the project site.

Post-Cretaceous rocks lie unconformably (i.e., younger strata were deposited after a period of erosion) on either the Cretaceous rocks or the crystalline basement, but are largely confined to coastal margins some distance from the project site.

In many instances, the crystalline rocks are covered by residual soils, or colluvial, and alluvial deposits. The colluvial deposits are typically located along the base of slopes and are formed as a result of the downslope movement of soil and rock by the force of gravity. The alluvial deposits are found to some degree in most drainages, with deposits of considerable thickness present in the major river valleys.

1.2.2 Site Stratigraphy

Several geologic units occur within the project site (Plate 1). In the lower portions of Gregory Canyon, a thin veneer of unconsolidated residual soils, colluvial, and alluvial deposits mantles a substrate of weathered tonalite. The topographic highs bounding the canyon are formed by igneous intrusive and metamorphic rocks with varying degrees of weathering. The following subsections describe in detail the geologic units that are exposed at the site.

Surficial Soils

According to Woodward-Clyde (1995), the topsoil units encountered in the area vary in thickness from about six inches to three feet, and are composed of silty sand, silty sand with clay, and silty sand with cobbles and boulders. In general, it is expected that the steeper, upper slope area of the landfill site include slightly thinner soil accumulations than the intermediate or lower slope areas. Underlying the topsoil are residual soil horizons or weathered bedrock.

Alluvium

Two alluvial units have been mapped at the lower elevations near the mouth of Gregory Canyon. The younger unit, Qal-1 is formed by overbank deposits from the active San Luis Rey river channel, which are interbedded with channel deposits from the Gregory Canyon drainage. These deposits are relatively thin and contain gravels, cobbles and boulders, supported by a sandy silt matrix. The older alluvial subunit, Qal-2, is a terrace remnant of older alluvium from the Gregory Canyon drainage.

The alluvial wedge pinches out to the south, before reaching the footprint of the proposed landfill development. The wedge thickens to the north until eventually it merges with the channel deposits of the San Luis Rey River. Well GMW-2, near the mouth of the canyon, encountered a 50-foot section of alluvial deposits before reaching the underlying bedrock.

Colluvium

Colluvium forms a veneer over most of the surface of the proposed landfill site. In most instances it consists of silty sand with rock clasts that range in size from gravel to very large boulders. Finer-grained deposits, largely devoid of rock clasts, were encountered in test pits located at the southern end of the canyon (Figure 1-2). Older colluvium was also encountered in some of the test pits, and consisted of clayey sand to sandy clay with varying rock content and slight to moderate cementation.

Rock clasts exposed at the surface of the colluvial veneer vary from gravel- to boulder-size material. Boulders of leucogranodiorite, some in excess of 20 feet in maximum dimension, are present along much of the eastern sideslopes. Based on borings drilled during previous investigations, it appears that boulders are extensive in the subsurface (Attachment 1).

The thickness of the colluvial deposits in the landfill site area is highly variable. Cross-section interpretations by Geraghty & Miller (1990) show thickness variations from 2 to 50 feet. The upper slope area is likely to be underlain by thin colluvial deposits and surficial soils formed on highly weathered crystalline rock. Debris chutes and drainage channels may be locally backfilled with colluvium of moderate thickness, but in general, the upper slopes are not likely to be underlain by thick, laterally continuous deposits of colluvium. Lower slope areas are expected to be underlain by much deeper and laterally extensive colluvial deposits consisting of a matrix of silty sand and clay around larger cobbles and boulders.

The current grading plan calls for removal of surficial soil and colluvium over the entire footprint of the landfill.

Bedrock

Larsen (1948) used the term Bonsall Tonalite to describe the rocks underlying the western ridge adjacent to Gregory Canyon, and the term Indian Mountain Leucogranodiorite to describe the light-colored, bold outcrops of granitic rock underlying the eastern ridge of the site area. Larsen (1948) also mapped an intervening band of metamorphic rock along the lower slopes of the eastern ridge, which he correlated with the sedimentary Triassic/Jurassic Bedford Canyon Formation; rocks of this unit have relict volcanic textures, however, and are probably best correlated with the Jurassic Santiago Peak volcanics.

The contacts between all three units are intrusive, albeit different in nature. The main body of the leucogranodiorite is in intrusive contact with the metamorphic band of rocks midway along the easterly slope of Gregory Canyon. The contact zone is narrow and abrupt where it can be observed, and has the characteristic features of sharp intrusive contact,-with apophyses[1] and dikes[2] extending from the leucogranodiorite into the metamorphic rock. No evidence of shearing is observed in outcrop.

The intrusive contact between the tonalite and the metamorphic wedge is somewhat transitional because of the effects of partial melting. Mafic or intermediate magmas (gabbro to tonalite) are emplaced at a relatively high temperature (1,200° to 900° C), so the contacts between them and the host rock tend to be anatectic (i.e., they are accompanied by partial melting of the pre-existing rock). The pre-metamorphic rock fabric can be completely obliterated by migmatization (i.e., development of a banded aspect in the rock as a result of partial melting), so along the contact zone it is not always easy to discriminate between the intrusion and the host rock. The intrusive nature of the contact has been documented at several field locations, however, and is characteristically irregular and intricate. No evidence of shearing is observed in the outcrop and the contact lacks the planar expression expected of a shear zone.

In response to comments received on the draft EIR, GLA prepared a technical memorandum (GLA, 1999) to clarify several issues, including the nature of the metamorphic/igneous rock contact. The following section summarizes the discussion from this technical memorandum, including photographs taken of these contacts provided in Attachment 2. Attachment 2 includes a series of photographs to illustrate the contacts

[1] Apophysis is defined as a branch from a vein or fracture that has been filled by the injection of a larger intrusive body.
[2] Dike is a tabular body of intrusive magma that cuts across the massive rocks.

of the metamorphic rocks with the leucogranodiorite (on the east) and with the tonalite (on the west). In this attachment, the location of each photograph is indicated on Figure 1.

Attachment 2, Figure 2 shows a sharp intrusive contact without evidence of shearing, and an apophysis of the leucogranodiorite "poking" through the amphibolite that forms the metamorphic wedge. Figure 3 shows a sharp but irregular contact, with a pegmatitic dike extending from the leucogranodiorite into a projection of the amphibolite. Figure 4 shows another sharp but irregular contact, with pegmatitic dikes extending into the metamorphic rock. In this photograph the presence of bold outcrops of leucogranodiorite is noted beyond the contact.

The intrusive contact between the tonalite and the metamorphic wedge is shown in Attachment 2, Figures 5 through 7. However, both rocks are very similar in color, so the photographs are not as striking as those described in the previous paragraph. In Attachment 2, Figure 5 shows an irregular intrusive contact, with a "relief" of about 3 feet. Attachment 2, Figure 6 shows a close-up of this contact, which is characteristically irregular and intricate. Attachment 2, Figure 7 shows a different contact between the tonalite and the metamorphic rocks, this time with a "relief" of about 6 feet. The photographs (Attachment 2, Figures 2 through 7) indicate that the contacts between the units are not faults.

Metamorphic rocks (TJm). The metamorphic rocks present along the easterly slopes of Gregory Canyon form a north-south-trending belt of older rock that was intruded by batholithic rocks (Plate 1). Specifically, the tonalite intruded and intermingled with the metamorphic rock, and both units were subsequently intruded by the leucogranodiorite.

The metamorphic rocks include amphibolites and metavolcanic rocks that locally exhibit some migmatitic[3] structure that resembles gneissic banding. The rocks are generally dark blueish gray, hard, and only slightly weathered with aphanitic to porphyroblastic[4] textures. Relict porphyritic textures suggest a volcanic protolith[5] for some of the units.

As indicated above, Larsen (1948) correlated these metamorphic rocks with the Bedford Canyon Formation (a sequence of mildly metamorphosed sedimentary rocks represented by deformed slates, schists, quartzites and localized occurrences of limestone), which is widespread in the Santa Ana Mountains. At Gregory Canyon, however, there are no outcrops of slates, quartzites or marbles, and there is a preponderance of metavolcanic

[3] Migmatitic texture is the name given to alternating dark and light colored bands in a metamorphic rock. The bands are formed in response to partial melting of the rock as it came in contact with magma. In contrast, gneissic banding is formed by segregation of dark and light colored minerals in the absence of partial melting or mixing with a magma. The dark and light bands in these two cases may look alike, but one forms only adjacent to a magma intrusion, whereas the other may be found over a large area.
[4] A rock is said to have aphanitic texture when the crystals that form it are too small to be observed by the naked eye. In contrast, the term porphyroblastic texture is applied to metamorphic rocks when a few large crystals, easily recognized by the naked eye, are set in a finely crystalline matrix. The same kind of texture in a volcanic rock is called porphyritic.
[5] A protolith is a parent rock from which a given metamorphic rock was formed by metamorphism.

rocks. It seems more reasonable to correlate the Gregory Canyon sequence with the Jurassic Santiago Peak volcanics, a unit composed of metavolcanic and metasedimentary rocks exposed elsewhere in San Diego County.

Of the 196 acres of the proposed landfill footprint, approximately 12 acres along the eastern side encroach over the outcrop of metamorphic rocks.

Tonalite (Kt). The tonalite that underlies the western slopes and the central portion of the Gregory Canyon area is an extensive rock unit in the area (Plate 1). Larsen (1948) referred to this rock unit as the Bonsall Tonalite. The tonalite is a dark gray rock, with medium to coarse crystallinity that includes a variety of related rock types such as gabbro. Other common variations noted in the tonalite are the locally veined and streaked appearance and the migmatitic fabric that is observed near the contact with the metamorphic rocks. The rock is also characterized by rare inclusions of the metamorphic rocks, and by numerous leucogranodiorite dikes that include fine-grained aplites[6] and coarse-grained pegmatites.

The tonalite is moderately to intensely weathered in most outcrops, although small cores of only slightly weathered tonalite form boulder knobs in the western flank of Gregory Canyon. Moderately weathered tonalite still preserves its phaneritic texture, but the weathered rock is less cohesive than the pristine rock, and the constituent minerals are slightly altered to oxides and clays, particularly along the edges. The intensely weathered tonalite has a granular texture that only vaguely recalls the original phaneritic texture, and is oxidized throughout. The constituent minerals are partially altered to oxides and clays, and disaggregate easily under pressure. Depth of weathering, as determined from exploratory drilling by Geraghty & Miller (1990), ranges between 65 feet (GMP-3) and 95 feet (GMW-2) (Attachment 1).

The tonalite comes in contact with the metamorphic rock along the easterly side slopes of Gregory Canyon, although the contact is typically covered by colluvium or obscured by surficial soils. Based on its map position, as inferred from isolated outcrops of both rock types, the contact appears to dip to the east at angles of 20° to 25°.

Leucogranodiorite (Klgd). The leucogranodiorite map unit is a light-colored, biotite-bearing granodiorite that forms the prominent mountain flanking the eastern side of Gregory Canyon (Plate 1). This prominent mountain is referred to as Gregory Mountain, but Larsen (1948) referred to it as Indian Mountain and to the light-colored rock as the Indian Mountain Leucogranodiorite. In hand specimen, the rock has a phaneritic texture with medium- to coarse-crystallinity, is light gray to buff, and has less than 5% dark minerals (biotite and iron-titanium oxides). Quartz, plagioclase, and potassium feldspar are the dominant felsic minerals.

[6] An aplite is a type of intrusive rock characterized by light color, abundance of quartz and potassium feldspar, and a fine granular texture that resembles the texture of sugar. Aplite is generally found forming dikes.

Besides forming the core of Gregory Mountain, the leucogranodiorite also forms dikes that cut older units. The dikes vary in thickness from less than an inch up to five feet, and in most instances are pegmatitic. The degree of weathering of the leucogranodiorite is generally slight, as can be inferred from the bold outcrops of Gregory Mountain. The dikes, on the other hand, vary in degree of weathering from low to moderate. Moderately weathered dikes are pervasively oxidized and have "cloudy" feldspars, but still preserve their phaneritic texture.

The main body of the leucogranodiorite is in intrusive contact with the metamorphic band of rocks midway along the easterly side slope of Gregory Canyon. As shown in photographs included as Figures 2 through 4 of Attachment 2, the contact zone is narrow and abrupt where it can be observed, but is generally buried under talus. Based on its map position, as inferred from the abrupt change in topography, the contact is nearly vertical.

1.2.3 Soil Resources and Engineering Properties

The soils on the site are alluvial and colluvial, or generated from in-place weathering of the bedrock (residual soils). Based on mapping performed by the U.S. Soil Conservation Service (SCS, 1973), acid igneous rock (AcG) is generally exposed along the easterly slope of the site and soil, if present, generally consists of silty coarse sand (Figure 1-3). Since this soil type is generally composed of large boulders and rock outcrops, it is likely to have a high runoff potential. Erodibility will vary with soil development but is likely to be high to very high.

Two upland residual soils, Las Posas stony fine sandy loam (LrG) and Cieneba coarse sandy loam (ClG2), are exposed on the westerly slope of the canyon. Runoff in these areas can be rapid to very rapid, and the erosion potential can be high to very high. Sandy loam of the Fallbrook series (FaD2) has been mapped at the north end of the canyon. The runoff in this area is medium, and the erosion hazard moderate.

Cieneba very coarse sandy loam (CmrG) is mapped on the steeper slopes of the site, primarily north of SR 76. Runoff in this area is rapid to very rapid and the erosion hazard is high to very high. The Tujunga sand (TuB) is exposed below these slopes and is characterized by very slow to slow runoff and only a slight erosion hazard. Riverwash (Rm) is exposed in the San Luis Rey River stream channel and it is typically composed of sandy, gravelly and cobbly materials. Thin slivers of Visalia sandy loam (VaA and VaD) are mapped on the southwest portion of the site. The VaA soil occurs on nearly level terrain, while the VaD soil occurs on moderate slopes. As a result, runoff for the nearly flat-lying VaA soils is very slow and the erosion hazard is slight. The steeper VaD runoff potential is medium with a moderate erosion hazard.

Laboratory testing was performed by WCC (1995) on soil samples obtained from test pits excavated at the site. A summary of the classification tests performed on the samples from the test pits shown on Figure 1-2 is presented in Table 1-1. Compaction tests, performed in accordance with ASTM D-1557 on material that was finer than the No. 4 sieve, were also completed and a summary of these test results is presented in Table 1-2.

Strength tests were performed on samples remolded to approximately 90 percent of their maximum dry density and a summary of these test results is presented in Table 1-3. The results of consolidation testing are presented in Table 1-4. Finally, laboratory permeability tests were also performed and these results are presented in Table 1-5.

1.2.4 Mineral Resources

San Diego County has a wide variety of mineral resources. Some of these, such as sand, gravel, and dimension stone, are essential to the construction industry and the region's economy. Sand and crushed rock are used as aggregate in Portland cement concrete and asphaltic concrete for construction. Blocks of granite rock (dimension stone) are quarried for decorative rock, monuments, and surface plaster. Of the rock products utilized in San Diego County, concrete-quality sand is in the shortest supply. The major river valleys are by far the most important source of sand in this area. Roughly two-thirds of available sand is in the San Luis Rey River. The San Luis Rey River through the project site is designated as a Mineral Resource Zone-2 (MRZ-2) by the California Department of Conservation, Division of Mines and Geology. The riverbed contains deposits of sand and gravel. The MRZ-2 zone is intended to preserve valuable mineral resources. However, it does not permit extraction of these resources without a major use permit. The MRZ-2 designation, which is an area containing potentially significant mineral resources, is confined to the bed of the San Luis Rey River.

The site is located 2.5 miles southwest of the Pala pegmatite district, which is a widely known source of gems (e.g., tourmaline, beryl and spodumene) and lithium minerals.

The district has an area of about 13 square miles and is underlain by granodiorite, tonalite, and gabbro of the Southern California batholith. The pegmatites themselves are most abundant in the gabbroic rocks, which are known collectively as the San Marcos gabbro, but are also present in reduced amounts in the granodiorites and tonalites. Most of the pegmatite occurs as tabular masses that trend north to north-northwest, and dip gently to moderately westward. They may have strike lengths of as much as a mile, and range from thin stringers (e.g., a small crack filling) to large dikes with bulges nearly 100 feet thick.

The bedrock substrate of Gregory Canyon is formed by rocks similar to those of the Pala district, and pegmatite dikes, albeit rare, have been identified in the course of geologic mapping. There is, therefore, a small possibility that lithium minerals might be found in the bedrock of the site. The probability of this occurrence is small, since 100 years of mineral exploration in and around the Pala district have not yielded mineral prospects in or near Gregory Canyon.

1.3 STRUCTURAL GEOLOGY

The tectonic regime of the region has changed significantly between the time of emplacement of the intrusions of the Bonsall Tonalite and the Indian Mountain Leucogranodiorite and the present. During the Mesozoic, a subduction zone was active off the coast of California, which led to magma generation and intrusion to form these units. Tectonic conditions changed during the Cenozoic, when subduction ceased, and transform faulting began on what is now identified as the San Andreas fault system (i.e., the underthrust of the Pacific plate was replaced by lateral shear between the plates). Horizontal motion started between 25 and 20 million years ago in the San Diego region (Atwater, 1970), and since then the tectonic "grain" of the Peninsular Ranges province has been dominated by strike-slip faulting along northwest-trending faults like the San Andreas, San Jacinto, Elsinore, and Rose Canyon faults.

The Elsinore fault zone is located approximately 6 miles northeast of Gregory Canyon, and is the closest of these large fault systems to the site. Like the rest of the regional faults, it is the result of the right-lateral strike-slip motion between the North American and Pacific plates, although the individual fault strands within the Elsinore fault zone may have strike-slip, normal, or thrust fault motions[7] as a result of complex local fault geometries (Lamar and Rockwell, 1986). The northwest-trending fabric of the fault zone also results in distinctive structural features, including large-scale structural depressions like the Elsinore Trough, and structural highs such as the Agua Tibia Mountains.

Of more immediate interest to the structural setting of Gregory Canyon is the fact that the "block" between the Elsinore fault zone to the northeast and the Rose Canyon fault zone to the southwest is under a shear stress regime (Figure 1-1). In effect, the area between both fault zones is being "wrenched" clockwise by the relative motion along these faults. Under these conditions, north-oriented extensional fractures form. This is the most likely explanation for the predominance of north-striking fractures on the site, and for the dominant orientation of topographic lineaments in the region.

1.3.1 Regional Faults

Several active faults exist within 60 miles of the proposed Gregory Canyon landfill site. These include the San Andreas, San Jacinto, and Elsinore fault zones, as well as the offshore portions of the Rose Canyon fault zone (Figure 1-1). These fault zones have an overall trend to the northwest, and right-lateral, strike-slip sense of movement. The closest approaches of the different faults to the site are 54 miles for the San Andreas fault, 30 miles for the San Jacinto fault, 6 miles for the Elsinore fault, and 25 miles for the Rose Canyon fault.

<u>San Andreas fault.</u> Based on the large number of historic earthquakes generated along the San Andreas fault, Wallace (1970) estimated that in any given year there is a 20% probability that an earthquake of magnitude (M) 6 would occur somewhere along the 600 miles of the San Andreas fault, and that there is a 1% probability that a magnitude 8 earthquake would be generated in any given year (in 1857, movement along the right-lateral, strike-slip San Andreas fault generated an earthquake with an estimated

[7] Faults are classified in three types according to the tectonic stress that formed them. Faults formed by the lateral shear of one rock mass against another are called strike-slip faults. Faults formed under an extensional tectonic regime, and showing surficial displacements, are called normal faults. Finally, those formed under a compressional regime, and showing surficial displacements, are called reverse faults.

momentum magnitude larger than 8.0 in the Fort Tejon area). In contrast, the trenching and geochronometric studies of Sieh (1978) in Pallett Creek suggest annual probabilities of 0.005 to 0.003 for magnitude 8 earthquakes.

For the purpose of evaluating seismic hazard, the California Division of Mines and Geology (CDMG) has estimated the Maximum Credible Earthquake (MCE) of earthquakes along the San Andreas fault – Southern Segment to be M7.4 (CDMG, 1996).

San Jacinto fault. The San Jacinto fault extends more than 120 miles from northwest of El Centro to northwest of San Bernardino. This fault has been the source of numerous micro-seismic events in modern history. At Superstition Hill, just north of the international border, a M6.6 event occurred in November 1987. Another recent rupture zone, as suggested by aligned fault scarps, extends across Borrego Mountain (San Diego County) and was the source of a magnitude 6.8 seismic event in 1968. The Anza section of the fault extends northwestward from the Borrego Mountain section and generated a magnitude 6.8 event in 1918. Finally, there was an 1890 event along the San Bernardino Valley section of the fault, in which surface lateral displacement was estimated at 1.4 + 0.4 m. Blake (1993) estimated the long-term slip rate of the Lytle Creek section of the fault at 10 mm/yr.

For the purpose of evaluating seismic hazard, the MCE value for earthquakes along the San Jacinto-Anza fault segment (the highest magnitude segment near the site) was estimated to be M7.2 (CDMG, 1996).

Elsinore fault. The Elsinore fault extends 150 miles from the Mexican border to the northern edge of the Santa Ana Mountains. Five earthquakes of magnitude greater than 5 have been generated along this fault during the last 100 years, three of which had epicenters near Lake Elsinore. According to Durham and Yerkes (1964), the Whittier section of this fault may have been active since Miocene time, as evidenced by the thickness and distribution of Cenozoic strata. According to Blake (1993), the long-term recurrence interval for magnitude 7 events is estimated at 100 years, from which an annual probability of occurrence of 1% can be calculated. Lamer and Rockwell (1986) estimated the long-term slip rate at 6 mm/yr.

For the purpose of evaluating seismic hazard, the CDMG has estimated the MCE of earthquakes along the Elsinore-Temecula and Elsinore-Julian fault segments were estimated to be M6.8 and M7.1, respectively (CDMG, 1996).

Rose Canyon/Newport-Inglewood fault. The offshore Rose Canyon/Newport-Inglewood fault zone extends more than 150 miles from the international border to Newport Beach and includes a 1,000 to 15,000-foot wide zone of strike-slip faults, folds, and related thrust faults. Of immediate interest for the project is the Del Mar segment, which extends from the latitude of Carlsbad to the latitude of La Jolla.

With respect to historical seismic activity, rupture along the northernmost segment of the fault (the South Los Angeles segment), resulted in the 1933 magnitude 6.3 Long Beach earthquake. In addition, where on shore, the fault zone has significant micro-seismic activity, while offshore seismicity south of Newport Beach decreases by an order of magnitude. For the purpose of evaluating seismic hazard, the MCE value for earthquakes along the Rose Canyon fault was estimated to be M6.9 (CDMG, 1996).

1.3.2 Local Structural Geology

Lineament Analysis

GLA (1997) inspected historical aerial photographs in order to identify potential structural discontinuities in the area of the proposed GCLF. Six sets of aerial photographs were used in the lineament analysis of the site.

The large-scale lineaments identified on and around the proposed footprint of the landfill are shown on Plate 1. On this map, lineaments have been defined by 1) single stretches of a ravine, and accordingly many of them are simple "shortest and steepest" paths for surface water drainage; 2) on the base of geomorphology (e.g., alignment of topographic saddles, linear cliff scarps) or tonal differences; or 3) well defined fractures (as in Gregory Mountain), or dikes.

In the small-scale photographs (1:42,500 to 1:65,000), Gregory Canyon seems to be straight, but in the large-scale photographs it does not appear to be truly "linear". At the large scale, as shown on Plate 1, a very short linear segment is identified near the head of the canyon (A on Plate 1), a tonal lineament off the thalweg of the canyon to the west (B), and a longer linear segment near the mouth of the canyon (C). There is also a set of three lineaments that are subparallel to the canyon, off the thalweg to the east (D).

Perpendicular to the length of the canyon, on the north are the geomorphologic lineaments defined by the cut of the San Luis Rey River (E), and a tonal lineament defined by the transition from grass to scrub vegetation (F). Toward the middle of the canyon, on the west flank, there are four steep ravines (G through J), but they do not seem to have corresponding lineaments east of the thalweg.

The leucogranodiorite, which crops out along the eastern portion of Gregory Canyon, is criss-crossed by joints, but in this area no lineaments were identified in the photographs that might suggest that the joints extend into the metamorphic wedge or the weathered tonalite to the west.

Aerial photograph review also included inspection of lineaments outside of Gregory Canyon. However, the lineament analysis did not disclose regional, through-going discontinuities across the footprint of the site. Other lineaments (e.g., D) appear to converge toward the Gregory Canyon alignment, and no lineaments have been identified that diverge from it.

Discontinuities at outcrop level

Inspection of the limited bedrock exposures indicates that structural discontinuities (joints, dikes) are common in the rocks that form the substrate of the canyon. In order to evaluate orientation, type, and characteristic spacing of these discontinuities, three "lines" were cleared of vegetation and cover soil (Plate 1), and the structural attitude of all observed discontinuities along them was measured. Line 1 was exposed along the floor of the north-trending road that runs mid-slope along the west flank of the canyon, and had a total length of 530 feet. Line 2 was excavated along the wall of the east-trending road that descends in a straight line from the western flank into the thalweg of the canyon; the wall could not be properly cleaned and this 75-foot line is thus of limited use in characterizing spacing. Line 3 was cleared along the floor of the same road, and had a total length of 220 feet.

An interpretation of structural orientations was performed using stereographic projections, to represent and analyze the three-dimensional data in two dimensions. The stereographic plots of the fracture data taken from 424 measurements in outcrop are provided in the Phase 5 - Hydrogeologic Report (1997). In summary, the combined structural data suggests the existence of four directions of preferred orientation:

	Dip direction	Strike direction	Dip angle	Dominant feature
Direction 1	270°	360°	65°	Fractures
Direction 2	90°	360°	80°	Fractures
Direction 3	255°	345°	60°	Dikes
Direction 4	330°	60°	65°	Dikes

If the structural attitudes of fractures and dikes are plotted separately, the stereonet plot for the fractures has primary maxima that correspond to Directions 1 and 2 in the table above, whereas the plot for dikes has maxima that correspond to Directions 3 and 4.

Spacing between discontinuities, and patterns of spatial distribution, can be characterized through the use of standard statistical techniques, and the discontinuity data of Gregory Canyon were tested for randomness and uniformity.

Results of the randomness analysis indicated that the data from Line 1, which has a general north-south orientation, appear to be randomly distributed, while the data from east-trending Line 3, do not fit the random distribution. The difference may be related to the orientation of the lines, the general dominance of north-trending discontinuities, and the fact that the east-trending Line 3 had a better chance of intersecting the more abundant north-trending discontinuities than Line 1.

Spacing between discontinuities in Lines 1 and 3 was also evaluated. In the case of Line 1, 57% of the spacings are less than or equal to 2 feet, and 9% of the spacings are larger than or equal to 9 feet. For Line 3, in contrast, 91% of the spacings are less than or equal to 2 feet.

The intersection of each pair of planes defines a line in 3-dimensional space, whose orientation can be expressed in terms of plunge direction (the azimuth of the projection of the line on the horizontal plane) and plunge angle (the vertical angle of the line with respect to the horizontal), as follows:

	Plunge direction	Plunge angle	Formed by the intersection of:
Intersection line A	180°	0°	Direction 1 and Direction 2
Intersection line B	222°	55°	Direction 1 and Direction 3
Intersection line C	300°	62°	Direction 1 and Direction 4
Intersection line E	176°	19°	Direction 2 and Direction 3
Intersection line F	16°	56°	Direction 2 and Direction 4
Intersection line I	286°	57°	Direction 3 and Direction 4

The outcrop fracture data summarized above indicates the apparent predominance of north-striking discontinuities, and the relative paucity of east-striking discontinuities. The presence of a significant number of discontinuities with other orientations would enhance interconnection of the fractures.

1.3.3 Local Faults

Faulting was evaluated by WCC (1995) for the project site and surrounding area based on a review of geologic literature, large- and small-scale stereo aerial photographs, and field reconnaissance. The closest mapped faults to the site are an east-northeast-trending fault first located by Jahns and Wright (1951), and a shear zone described by WCC (1995) (Figure 1-1). The Jahns and Wright (1951) fault is the only nearby fault depicted in the 1994 Fault Activity Map of California (Jennings, 1994), and it shows no evidence for Cenozoic displacement (i.e., it is an inactive fault).

With respect to the potential shear zone located across SR 76, WCC (1995) noted that there is no evidence to support continuity of the high-angle shear feature (such as lineations or similar exposures) along its general strike to the north or south. From this they inferred it to be a localized feature. GLA (1999) inspected this outcrop, collected six selected samples for thin-section petrography, and carefully inspected its possible extensions to the north and south (on the flank of Gregory Mountain across the San Luis Rey River). As a result of these analyses, it was concluded that the so-called shear zone is actually a steep planar contact between metamorphic rocks and hydrothermally-altered gabbro. The gabbro is brecciated (i.e., the rock is not homogeneous, but rather it is formed by an agglomeration of angular blocks), but the fragments do not show tectonic shearing, alignment, or fault gouge between them (photographs of this outcrop are provided in Figures 9 and 10 of Attachment 2). A couple of hundred feet east of the contact the rock becomes progressively less brecciated and hydrothermally altered.

The 200-foot zone of brecciated gabbro does not have the characteristic features of a fault zone. Since such a thick "fault zone" would be indicative of a major fault, shearing should be pervasive. However, since there are no prominent shear planes in this portion of the outcrop a fault origin is not interpreted. In addition to the general lack of shearing, careful inspection of the ravines to the north of the outcrop did not disclose continuation of the breccia, and GLA (1999) concluded that it has the shape of a vertical chimney, rather than a planar feature. The limited extent of the breccia zone in the strike direction is uncharacteristic of a major fault zone. In contrast, intrusive breccia chimneys or pipes are common in shallow plutons (e.g., Norton and Cathles, 1974), and characteristically show the effects of hydrothermal alteration.

To confirm this interpretation GLA (1999) made a careful inspection of the north flank of Gregory Mountain, where the contact would be reasonably expected to project if it were an extensive planar feature (Figure 11 of Attachment 2). This inspection identified only non-brecciated tonalite/gabbro along the northern flank of Gregory Mountain, thus confirming that the gabbroic breccia does not extend across the San Luis Rey River.

Finally, GLA performed a careful inspection of the outcrops created by SR 76. These outcrops are in direct alignment with Gregory Canyon itself, and expose a continuous non-brecciated and non-faulted section of weathered tonalite/gabbro. This continuous section is further evidence that a major fault zone does not extend along the axis of Gregory Canyon.

1.4 GEOLOGIC HAZARDS

The following sections provide a summary of the geologic hazards that might be associated with surficial processes including landslides, rockfalls and debris flows. In addition, geologic hazards associated with deep-seated processes from faults and seismic hazards are also discussed below.

1.4.1 Landslides

The potential for landsliding was evaluated by WCC (1995) based on review of stereo aerial photographs and field reconnaissance study. Geologic or geomorphic features characteristic of landslides were not observed, and given the crystalline nature of the underlying bedrock materials, landsliding is not expected to create a significant hazard at this site.

1.4.2 Rockfalls

Rockfalls are abrupt movements of independent blocks of rock that become detached from steep slopes. Falling rocks can reach the base of a slope by free-falling, bouncing, rolling down the slope surface, or by some combination of the above. There is clear evidence that rockfalls have occurred at the site during mass wasting of Gregory Mountain located east of the site.

1.4.3 Debris Flows

Earth, mud, and debris flows form when a mass of unconsolidated sediment is mobilized by sudden ground vibration (e.g., an earthquake) or by a sudden increase in weight and pore water pressure (e.g., after soaking of the soil by heavy rains). The initial movement of a flow is enhanced by steep topography and deforestation, but once mobilized, flows can spread over gently sloping terrain.

Debris flows cannot be forecasted, but the susceptibility for formation of debris flows on any given site can be estimated by looking for evidence of previous flow events. GLA (1998) reviewed aerial photographs of the site, and concluded that there is a mappable deposit of poorly-sorted colluvium material that could have been formed as a debris flow deposit (Qco [Plate 1]). The deposit forms a landform with a rough lobate (e.g., rounded) shape and comparatively steep boundaries, but lacks levees or pressure ridges, and so could also have been formed by erosion of an older colluvial fan.

1.4.4 Faults

As stated in Section 1.3.3 above, there are no active faults in the immediate area of the Gregory Canyon site. In addition, there is no evidence of a major fault zone extending along the axis of Gregory Canyon.

The Elsinore fault zone, located approximately six miles from the site, is the most likely source of strong seismic motion in the area of the proposed Gregory Canyon landfill site. The Elsinore fault extends 150 miles from the Mexican border to the northern edge of the Santa Ana Mountains. Five earthquakes of magnitude greater than 5 have been generated along this fault during the last 100 years, three of which had epicenters near Lake Elsinore.

As stated above, to apply an additional margin of safety, the site was designed for the Maximum Credible Earthquake (MCE). An MCE event of M7.1 was used for the Elsinore-Julian Fault and M6.8 was used for the Elsinore-Temecula Fault (CDMG, 1996). For this analysis, a deterministic estimation of the peak horizontal acceleration was calculated for the MCE using the computer program EQFAULT (Blake, 2000). A series of attenuation relationships, based on published seismological papers, were used to produce the range of peak horizontal accelerations presented below.

Maximum Credible Earthquake

Fault Scenario	Range	Mean/Average
Elsinore-Temecula fault M6.8 earthquake 5.5 miles (8.8 km) from the site	0.2g to 0.39g	0.34g
Elsinore-Julian fault M7.1 earthquake 6.0 miles (9.6 km) from the site	0.22g to 0.40g	0.35g
San Andreas fault-Southern Segment M7.4 earthquake 47.7 miles (76.7 km) from the site	0.04g to 0.07g	0.06g
San Jacinto-Anza fault M7.2 earthquake 28.1miles (45.3 km) from the site	0.08g to 0.11g	0.09g
Newport- Inglewood/Rose Canyon fault M6.9 earthquake 22.6 (36.4 km) from the site	0.08g to 0.12g	0.09g

From these estimates, assuming a MCE event, it appears that the area of the Gregory Canyon proposed landfill site expansion is likely to experience short-period peak horizontal accelerations between 0.2g and 0.4g for a near-field earthquake and about 0.1g for a far-field earthquake.

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